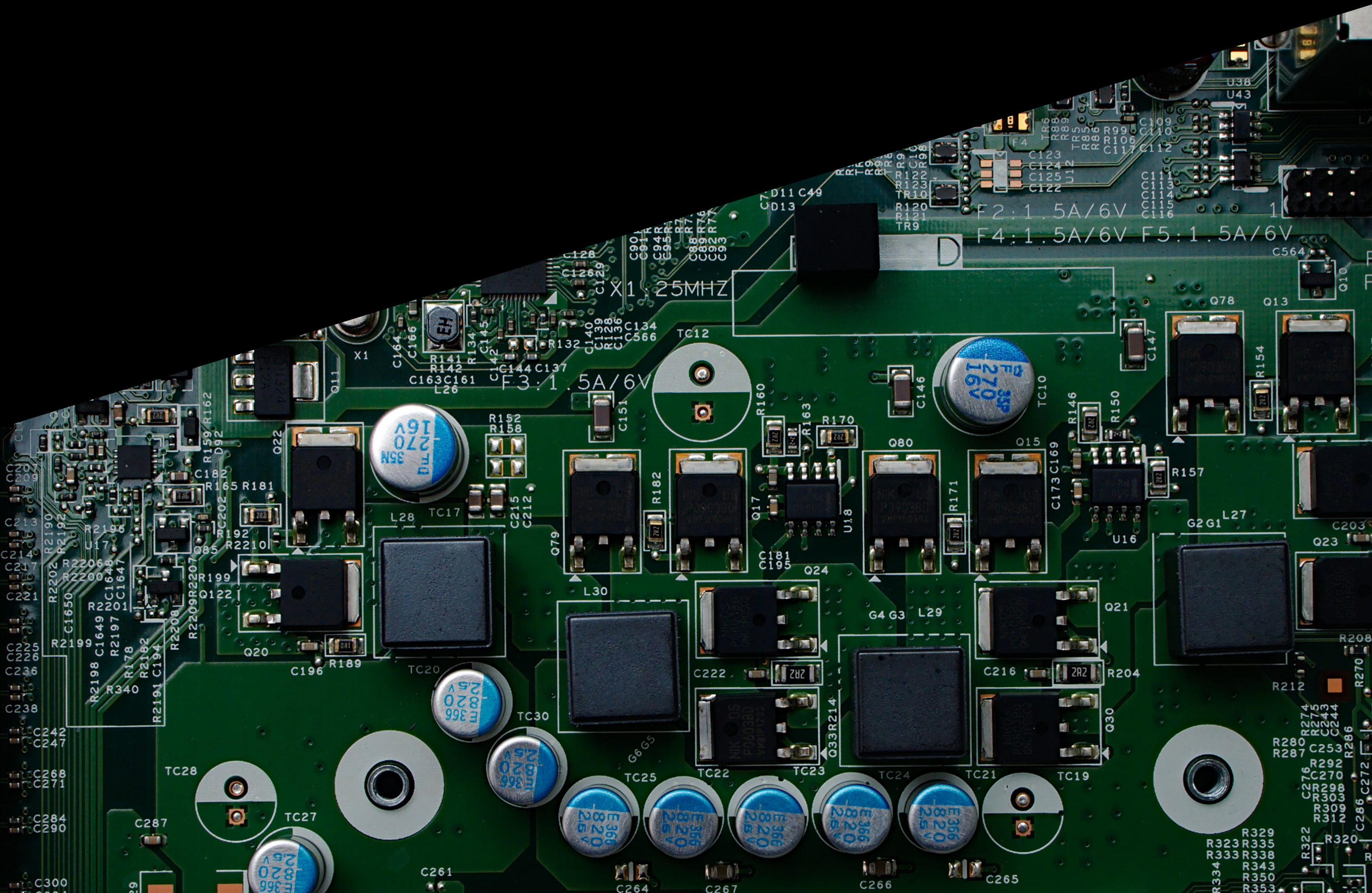
INSTRUMENTAL

A guide to engineering builds: EVT DVT PVT



INTRODUCTION

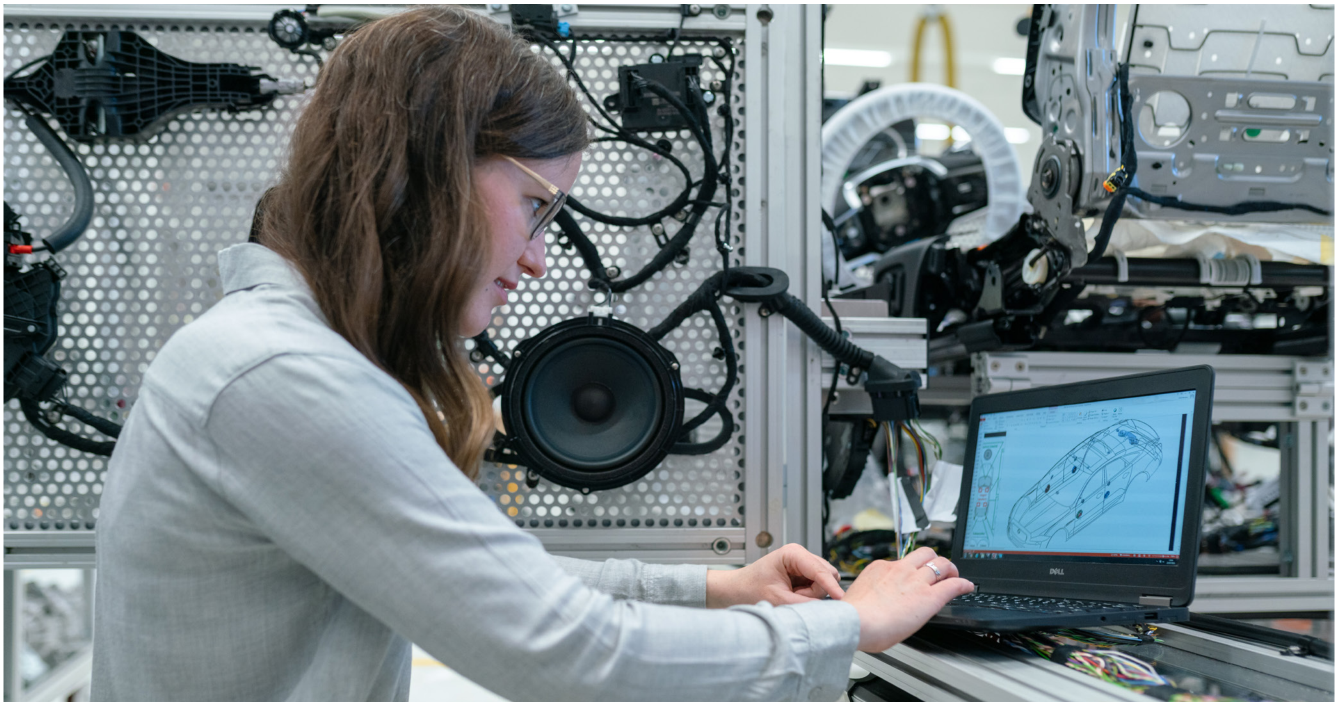
While software engineers may write code, hardware engineers speak it. We love our three-letter acronyms (TLAs): EVT, DVT, PVT, MP; OK, NG, FA, CA; PD, EPM, OPM; PRD, DRP, BOM. Goodness, how do we even understand each other?

Instrumental spends a lot of time speaking with engineers at hardware companies — large and small — about their manufacturing pain points. In the course of those conversations, we are always talking about those pain points in the context of product maturity and the builds: EVT, DVT, PVT, and MP. While a few companies use slightly different nomenclature, the basic structure is consistent: you build prototypes of the design multiple times to zero in on the final, mass production ready design.

This Guide Features:

- **Definitions** of common acronyms
- **Workflows** and example processes
- **Schedules** and reasons for delays
- **Diagrams** that provide perspective

Interestingly enough, there are differences in understanding across the consumer electronics industry on what EVT and DVT product maturity even mean. Internet searches do not return satisfying results, so early hardware companies have this question a lot. Instrumental put together this guide to explain the builds, schedules, and common problem areas that hardware engineers work through.



PROTO

The Proto build is a small test run of key product concepts to gain confidence that they can work — potentially a combination of different form factors including looks-like and works-like.

PURPOSE: to understand risks around specific modules or designs, usually with multiple variants in low quantities, such as:

- Fragility of coverglass in drop test with different adhesives, perhaps done on dummy housing bucks
- Waterproofness of five different button seal designs

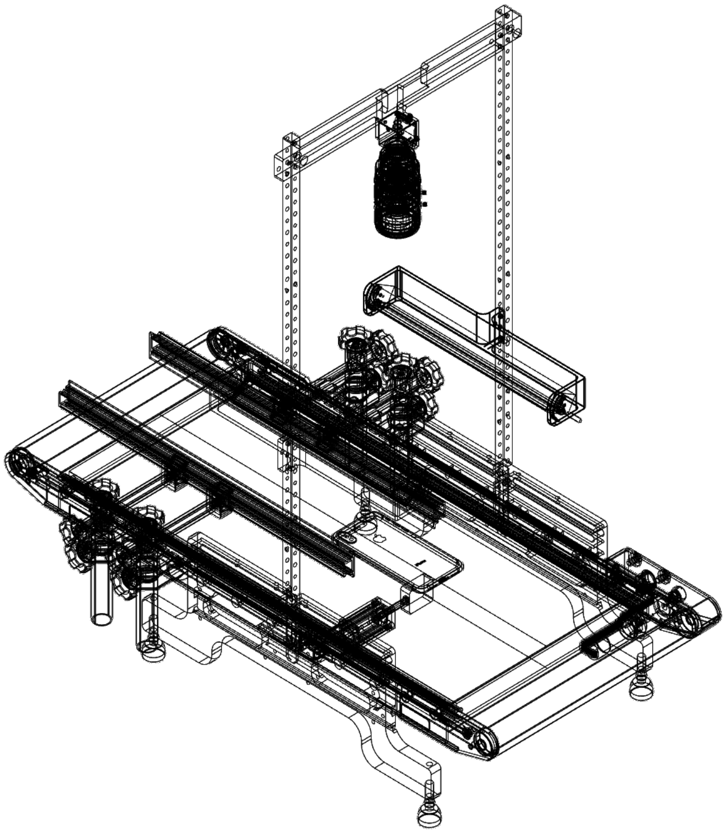
TYPICAL QUANTITIES: 10 or fewer, sometimes no "full systems" are even built

- Parts may be "stand-ins" or rapidly prototyped (which may change results for better or worse)
- Sub-modules do not have to be integrated — units may be "works like" or "looks like"

THINGS THAT GO WRONG:

- Part quality is poor, resulting in incorrect dimensions or an interference was missed in the CAD (3D model), so parts do not fit together and have to be modified by hand
- Pin 1s on connectors were not correctly mapped, so things do not electrically work even when plugged together
- The intended design fails miserably during testing and needs to be redesigned

EXIT CRITERIA: one design concept for the product that the team has reasonable confidence is three major iterations or less from a mass-production worthy design



EVT (ENGINEERING VALIDATION TEST)

The EVT build is the first time you combine looks-like and works-like into one form factor, with production intent materials and manufacturing processes.

PURPOSE:

- To select the production intent design, sometimes from a build matrix of options
- To identify all of the issues that need to be fixed with that design

TYPICAL QUANTITIES: 100 to 1000

- Units must be fully functional and testable, made from the intended materials and with the intended manufacturing process, but may be from soft-tools (if you're using 3D printed parts, it's not EVT!)
- All functional test stations must be present and collecting data

THINGS THAT GO WRONG:

- A new revision of an intended design does not work after reliability testing
- Tighter than expected (or capable) tolerances are needed to meet the intended performance specifications — such as with an antenna element
- Depending on product complexity, up to ~40% of the units built may fail for a variety of functional or performance reasons and need to be analyzed
- Engineering has started the battle to get glue processes, hand-soldering, environmental seals, and other tricky steps under control

EXIT CRITERIA: one production-worthy configuration that meets all of the product requirements for functionality, performance, and reliability

DVT (DESIGN VALIDATION TEST)

The DVT build is supposed to be one configuration of your production-worthy design, made of components from production processes (and hard tools) and on a line following production procedures. Very few companies actually stick to this requirement — because even if miraculously there are no outstanding issues, there may be parallel efforts to cut cost or increase yields that create additional configurations to build.

If you do have functional, performance, or reliability issues that are driving Plan B and Plan C configurations at this stage, it can be costly because each of those alternates needs to be built in "full quantity" to ensure that design can be fully mass-production qualified by the end of the build. That's the real test for whether you are at DVT or not: if you are running side configurations of 20 units, you are fooling yourself, and should call it EVT2.

PURPOSE:

- To verify mass production yields with one production-worthy design (one configuration for each shipping SKU)
- To qualify the first hard tool for every part in the assembly

TYPICAL QUANTITIES: 300 to 2000

- All parts should be from hard tools or mass production capable processes
- All functional test stations must be present with limits in place to understand true yields

THINGS THAT GO WRONG:

- High functional fallout rates — requiring the need for fast failure analysis and corrective actions
- Cosmetic yields are 0% — there may be an effort to try to track down and fix cosmetic aggressors, but it is usually fruitless because your cosmetic part suppliers are likely still shipping scratched parts (and you are having to waive them)
- At least one key process, such as gluing, is still not under control —
  - DOEs (there's another one! Design of Experiments, mentally replace with "experiments") are run with alternate glues or curing parameters
  - There are nightly calls with vendors demanding support or giving updates to hardware company executives

EXIT CRITERIA: high confidence in all corrective actions for any issue that causes unacceptable yields on units using mass production parts made from mass production tools.performance, and reliability

PVT (PRODUCTION VALIDATION TEST)

PVT is the “last build” — the units you are building are supposedly intended to be sold to customers, if they pass all of your test stations. PVT typically transitions directly into Ramp and Mass Production, or a Pilot build with no time gap.

PURPOSE: to verify mass production yields at mass production speeds

- Validate and qualify additional tools needed to support quantities for early ramp
- No parallel experimental units allowed (I have never seen this actually happen, but it is a goal that should be driven to for as long as possible)

TYPICAL QUANTITIES: 1K to 20K

- All units are intended to be sold to customers
- The build is potentially phased — red, yellow, green is common — indicating “maturity” of the production process, which includes a combination of operator training level, line speed, and line yield

THINGS THAT GO WRONG:

- A new revision of an intended design There is almost always at least one issue that is still outstanding at the start of PVT — this is likely the item at highest risk of impacting your schedule
- There is usually at least one vendor whose yields are way lower than expected, and because they cannot produce at the quantities promised, input is gated by their deliveries
- If you have a high cosmetic standard, your cosmetic yield likely starts at 0%. Unless you decide to loosen your standard, the conventional way to improve it is to knowingly input units to a 0% yield line and painstakingly seek places where damage occurs and improve them. This process can take weeks and hundreds or thousands of units. An Instrumental system can streamline and significantly accelerate this process

EXIT CRITERIA: mass production yields at mass production speeds on at least one line, and replication to other lines already started.

RAMP AND MP (MASS PRODUCTION)

PVT flows immediately into the phase of the program called Ramp, where parallel assembly lines are being brought up to increase daily output volume. Mass Production is a superset of Ramp and the sustaining production that follows.

PURPOSE:

- Bring up multiple lines in parallel to support high volume
- Continue to improve ongoing yield
- Qualify additional tools or vendors
- Make design changes based on returns, Early Field Failure Analysis (EFFA), or cost down efforts

THINGS THAT GO WRONG:

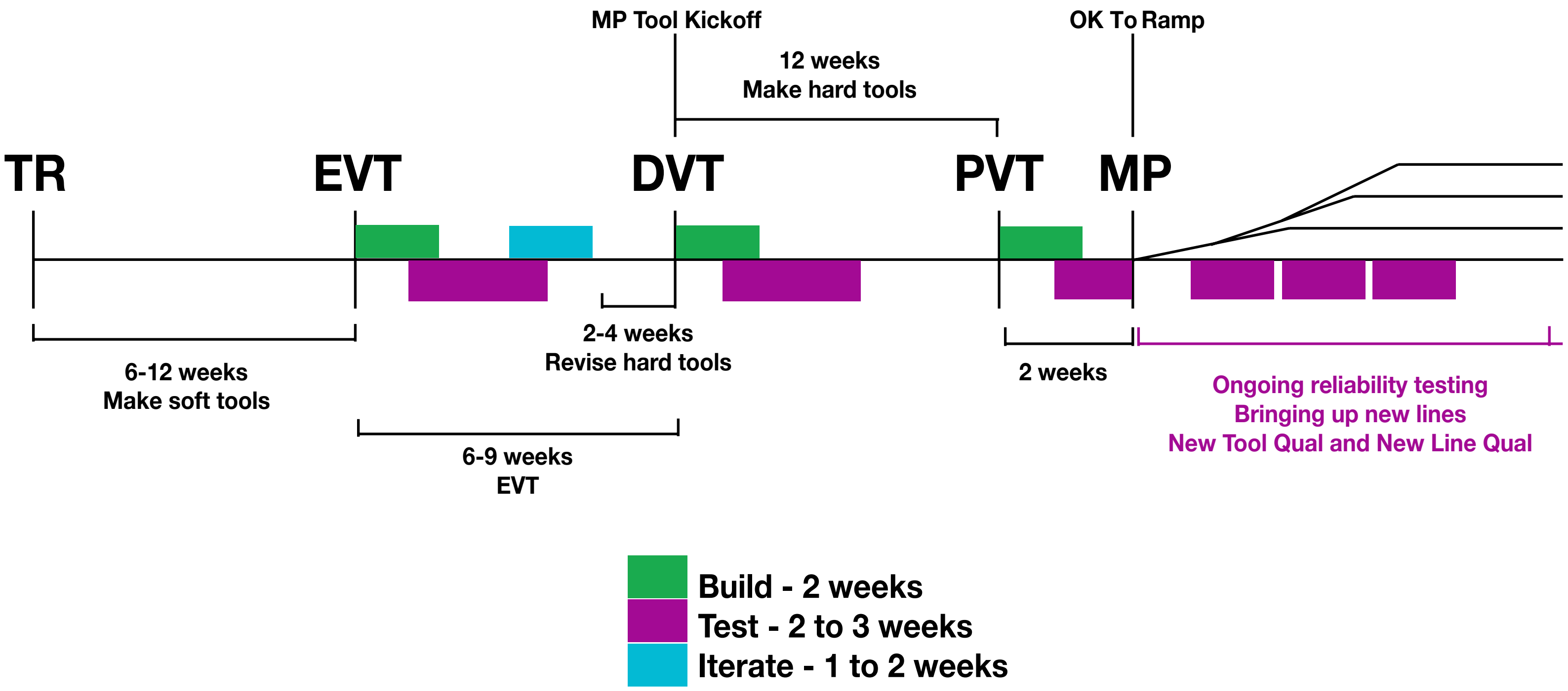
- Vendors change processing parameters or take down tools for maintenance, resulting in dimensional or quality shifts that can cause line failures
- Parts from unqualified tools are allowed on the line and cause failures A single-sourced part becomes the supply gate, usually due to ongoing yield issues
- Quality tends to decrease as engineering is pulled away and factory is left unsupervised

BEWARE OF XVT

Timing for the build process outlined above is driven by the need to iterate hardware in order to get the design right. That need often comes into direct conflict with the realities of the market: if you're building a toy, for example, it must be ready to ship for Christmas. This tension between the iteration process and the market-driven schedule can do weird and sometimes dangerous things to the development process. While there's much to discuss on that topic, we wanted to share a cautionary note about the nuclear option: XVT.

XVT is a fabrication of over-optimistic program managers and operations executives who believe that it's possible to enter a build with EVT parts and complete DVT exit criteria (the X being a stand-in for either an E or a D, where everyone crosses their fingers that by the end it's a D). XVT doesn't stand for anything, but if it did, it would be No Validation Test. Experienced engineers assert that investing massive DVT-scale resources into an EVT maturity design does not get your product out faster. If the schedule is really putting pressure on your design and you're contemplating cutting corners in the development process to stay on track, it is possible Instrumental may be able to help your team move faster.

THE TYPICAL HARDWARE DEVELOPMENT SCHEDULE



Hardware teams build their products by traversing through these phases and into mass production using the Build-Test-Iterate hardware iteration cycle.

Pictured above is a product development schedule representative of what a typical consumer electronics company might come up with and adopt. It is not an idealized schedule based on infinite time and resources, but rather an "optimistic" schedule influenced by the aggressive goals that are common for products being developed for competitive markets of all sizes and maturities. This type of schedule is the status quo.

SCHEDULE NOTES:

- During EVT, while the physical assembly may only take a week or two, reliability testing and other validation activities can take up to three weeks. Building and testing can (and often does) overlap – often there will be opportunity during the build to find and fix small issues, and create an issues list of what needs to be iterated. However, that list won't be fully complete until reliability testing concludes weeks after the build.

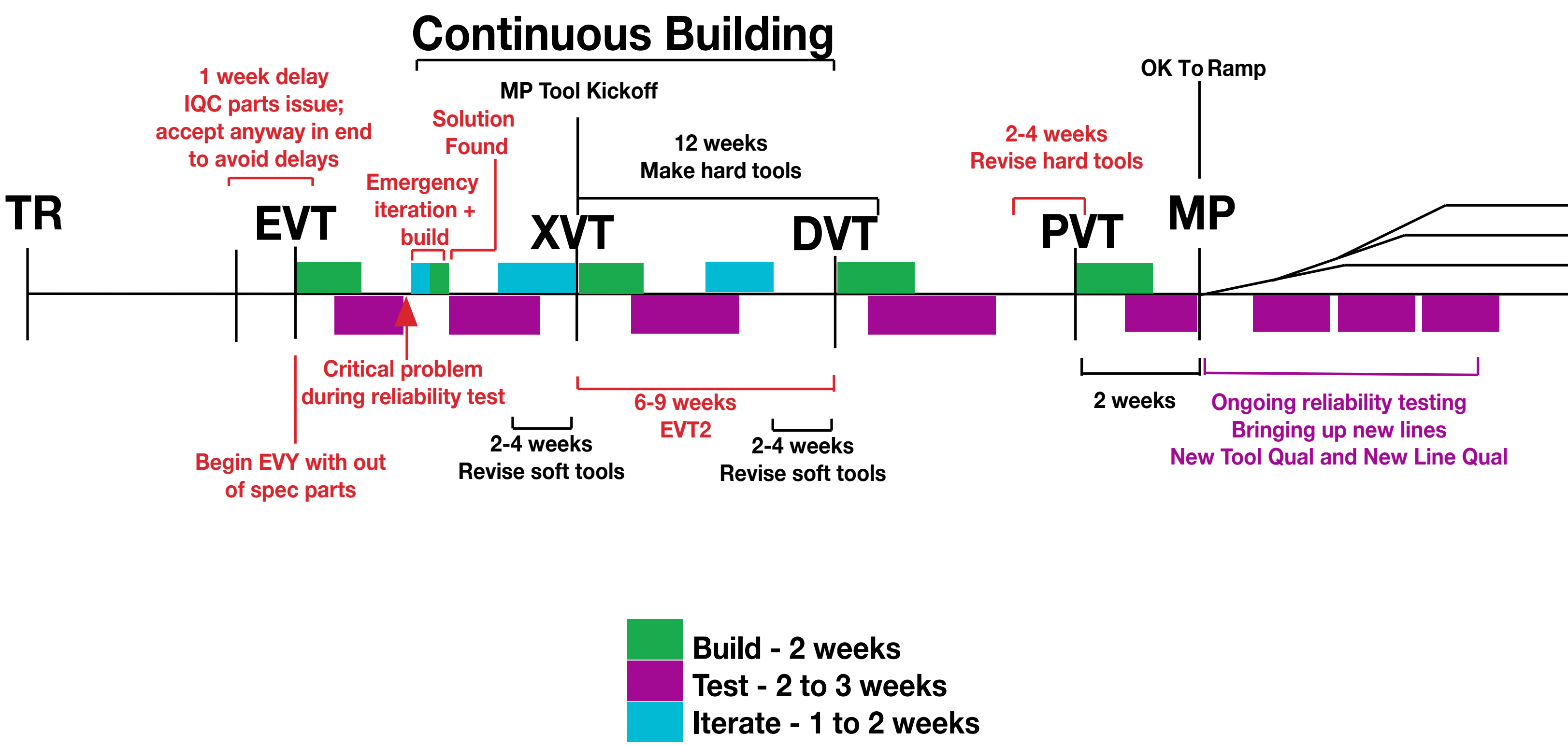
- Additional DOEs may be required after reliability testing – but it's rare for them to be explicitly scheduled beforehand.

HOW DELAYS HAPPEN

SCHEDULE NOTES CONTINUED:

- Instead of waiting for DVT validation to finish, most teams will kick off mass production hard tools in parallel with soft tool revisions at the end of EVT, in order to stack the DVT build with the typical 12 week tool fabrication time. This is the "middle ground" in terms of how aggressive you can get with the timing:
  - Ideal schedule: MP tool kickoff happens after DVT validation is complete.
  - Normal schedule (more aggressive): MP tool kickoff happens in parallel with or just before DVT
  - Extra aggressive schedule (danger!): MP tool kickoff happens in parallel with or just before EVTstarted.

Now that we've seen the expectation of how things typically go, it's time to look at the reality of how things actually go. The differences between expectation and reality are the things that lead to product delays. These are canonical examples of the kinds of things that nearly always "go wrong."



HOW DELAYS HAPPEN

Right away, you will see that the EVT-DVT-PVT progression was broken, with a "continuous build" situation taking its place, which ultimately resulted in a product delay of up to 15 weeks. If your product release target was the holiday shopping season, that could mean missing November/December and shipping in February instead. Let's take a closer look at what went wrong and how it affected the schedule:

ISSUE 1 : IQC / OQC SYNC-UP ISSUE
EFFECT: 4 DAYS TO 1 WEEK DELAY

Your upstream vendor's outgoing quality inspection (OQC) report showed no issues, but your final assembly site's incoming quality inspection (IQC) report is red all over. This is an incredibly common occurrence for supply chains with proper inspection. This typically causes a four day delay. Unless the parts are really bad, you will end up accepting them anyway and will likely build EVT with multiple out-of-spec parts, just four to seven days behind schedule.

ISSUE 2: A MAJOR DESIGN ISSUE DISCOVERED DURING RELIABILITY TESTING.

EFFECT: 6 TO 9 WEEK ADDITIONAL BUILD + 2 TO 4 WEEK ADDITIONAL TOOL REVISION

During EVT, partially through reliability testing, you find a critical problem. Common examples of "critical problems" might include:

- enclosures that change color in extended heat soak
- displays that degrade
- bubbles growing in fully laminated stacks
- product falling apart in strife testing

Generally speaking, it is prudent to expect to face at least one or two critical problems in any program (I've worked on programs with dozens). In order to recover, your team quickly designs some DOEs, identifies a candidate solution, and kicks off soft tool adjustments. The new fix is not validated yet, however, so while the next build is "DVT," everyone knows that the product isn't actually at DVT maturity – we could say its at "XVT".

This is the moment where you can fall into the trap of continuous building: in an attempt to avoid delay, your team stays on the original DVT schedule, and kicks off unvalidated MP tools on schedule. Unfortunately, more often than not you will find your XVT wasn't sufficient to roll right into MP, and you'll need to eventually add an additional build – as well as spend significant time and money to go back and modify your hard tools.

Instead, your team should just take the hit in advance and add the build as an EVT2. Since it's EVT2, you would hold off on MP tool kickoff until you reach a true DVT state. All in, if your team takes the EVT2 route, the delay will be six to nine weeks. If they take the continuous build route, the delay will be at least an additional two weeks longer because of the time it takes for additional tool modifications.

THE TRUE CAUSE OF PRODUCT DELAYS

Delays are caused by unrealistic, overly aggressive schedules which were designed to meet aggressive goals. Teams on these flawed schedules inevitably fall behind when they encounter an issue that should have been planned for but wasn't, and in response, may adopt flawed recovery modes – such as continuous building – that ironically exacerbate the problems further and lead to even more delay.

Adopting "fake schedules" simply doesn't work, and will only lead to problems. The correct approach to speed up product development is not to compromise the EVT, DVT, PVT process, but to instead target the speed of the Build-Test-Iterate cycle: to shorten the time between when a defect is created on the line, and when that defect is discovered and understood.

THE SECRET TO SPEED LIES IN THE HARDWARE ITERATION CYCLE

Again, there are two parts of the hardware development process: the fundamental build phases (EVT, DVT, PVT), and the iteration cycle teams use to traverse these phases (Build-Test-Iterate).

The product delays we see today are the consequence of companies trying to speed up the schedule, when instead the answer lies in speeding up the iteration cycle.

Hardware schedules should always:

- Plan for at least one major unexpected obstacle
- Aim for hard iterations, keeping parallel iteration to a minimum and only with structured DOEs
- Wait until after EVT reliability test results confirm a good design before kicking off MP tooling

Speed originates from the ability to collect and analyze data faster. On today's assembly line, there is a ton of information about units that is left uncollected (quickly forgotten in operator memory), unshared (siloed on the hard drive of a piece of equipment on the line), or even unobserved. No one person has a complete view of the line, process, and development status. Getting access to this "missing information" would enable teams to gain insights into units immediately, rather than having to wait for results from functional tests. Finding issues faster gives teams a head start on fixing them, and ultimately enables them traverse through EVT, DVT, and PVT on, or ahead of, schedule.

Instrumental's mission from CEO and Founder, Anna-Katrina Shedletsky

Manufacturing has a problem with global implications: 20% of every dollar spent in the industry is wasted – adding up to $8 Trillion, or 10% of the global GDP. The waste comes from errors in design, in the iteration of prototypes, in expensive failed tools, parallel developments due to lack of engineering confidence, lost time due to failures upstream, missing parts holding up lines, and more. While this has long been accepted as the cost of solving hard problems, Instrumental believes we can build better.

Started by two ex-Apple mechanical engineers who spent years on the factory floor, Instrumental is the culmination of the fundamental belief that manufacturing can be better and that the missing link is data. Engineers need real-time, product level data with tools that accelerate their current failure analysis workflows and enable remote monitoring of production. Engineers and manufacturers build better with

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sales@instrumental.com